Photorefractive Spatial Solitons

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Light solitons in space (spatial solitons) exhibit a dual behavior of both waves and particles. They form when light interacts with the medium of propagation in a manner that exactly compensates for diffraction. This results in self-trapping of the light beam. It is obvious, however, that, since the medium is required to modify its properties in the presence of light, a strong light-matter interaction is required, *i.e.*, the material must possess optical nonlinearities. All optical solitons that have thus far been discovered are a consequence of material nonlinearities that are proportional to the absolute light intensity (Kerr-like solitons). Therefore, they typically require intensities of the order of kW-MW/cm^2 for their operation threshold. On the other hand, photorefractive (PR) materials, which have been studied over the last two decades, possess strong nonlocal nonlinearities that do not depend upon the absolute light intensity. It was not initially obvious, however, that these materials are also capable of forming optical solitons.

We predicted the existence of photorefractive spatial solitons about two years ago.[1,2] The self-trapping effects occur when diffraction is exactly balanced by self-scattering (two-wave mixing) of the spatial (plane wave) components in the soliton beam. Since diffraction involves accumulation of phases that are linear with the propagation distance to each individual plane-wave component of the beam, it is desirable to balance it by nonlinear phase coupling. Photorefractive materials, however, typically exhibit amplitude coupling (energy-exchange interaction) due to a dominant diffusion transport mechanism for the redistribution of the photo-generated charge carriers. This, inherently, cannot compensate for diffraction, and therefore cannot form solitons. On the other hand, an external bias field (voltage) can cause strong phase coupling and is, therefore, required for the formation of PR solitons. Another consideration involves symmetry requirements. Diffraction, by its nature, is symmetrical about the axis of propagation. Since the photorefractive effect results from the electro-optic (Pockel's) effect, it possesses a complicated tensorial dependence on the angular propagation direction in the crystalline medium. We were, however, able to formulate the theory of spatial photorefractive solitons, extract their properties, and suggest configurations, materials, and crystalline orientations for practical experiments. Recently, we observed the first photorefractive spatial solitons.[3]

The experiment was performed in a 6 mm-long strontium barium niobate (SBN) crystal with a 10 µW laser beam from the 457 nm line of a cw argon-ion laser (intensity of about 200 mW/cm^2). The beam propagated along the crystalline axis, and DC voltage was applied along the c axis. Cross sections of spatial solitons varying from 10-30 µm (FWHM) were observed, with DC fields of about 400 V/cm. Higher voltages cause the nonlinear perturbation in the index to greatly exceed diffraction, and the PR solitons break down before reaching a temporal steady state. The experimental observation is depicted in the figure, which consists of scans across a series of cross-sectional images along the propagation axis. A top-view of the observation is shown on the cover of this issue of *OPN*. The soliton evolves from an arbitrary input shape and the final waveform is smooth, regardless of material inhomogeneities that are seen at the entrance face in the figure shown. Unlike Kerr solitons, which are stable only in a single transverse dimension, PR solitons are formed, and remain stable, in both transverse dimensions (although with different cross sections, owing to different Pockel's coefficients). The solitons are indifferent to light intensity, and maintain the same structure with intensity variations (the signature of the PR interaction). However, the solitons could be easily erased by light using an incoherent beam from a flashlight. Reversing the polarity of the applied voltage transforms the self-induced "positive lens" into a negative one, and causes the solitonic behavior to disappear. The result is a doubling of the diffraction.[3]

References

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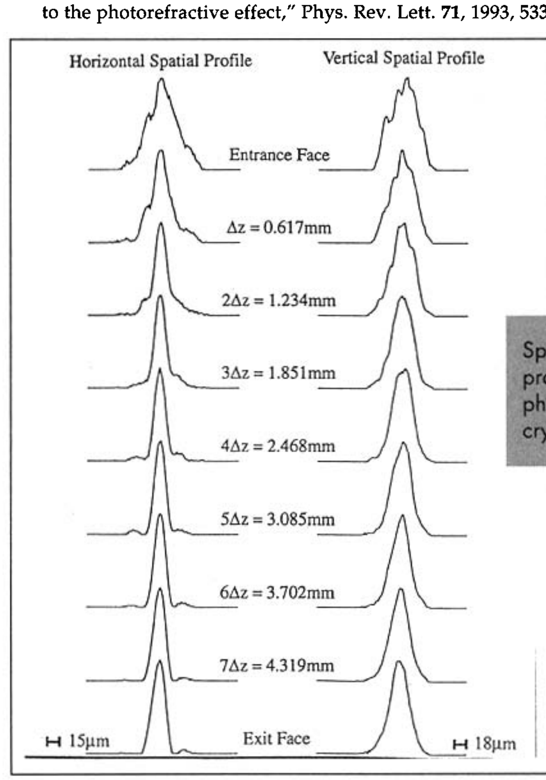
2. B. Crosignani *et al.*, "Self-trapping of optical beams in photorefractive media," JOSA B **10**, 1993, 446.
3. G. C. Duree *et al.*, "Observation of self-trapping of an optical beam due to the photorefractive effect," Phys. Rev. Lett. **71**, 1993, 533.



Spatial beam profiles inside the photorefractive crystal.